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1.—The "Greenstones" of South Western Australia

Presidential Address, 1960

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In preparing my Address for this evening I ırst looked back at some of the Addresses given y former Presidents of this Society whose nterests were in the same field as mine—that s the field of "hard rock geology"—and I find hat, naturally enough, since Western Australia orms the solid Precambrian nucleus of Ausralia, they all chose to speak about the Preambrian of Western Australia. My predecessor nd colleague in the Geology Department at he University, the late Professor Clarke, in 1923 poke about "The Precambrian succession in ome parts of Western Australia," the late Mr. Gibb Maitland in 1927 dealt with "The volcanic istory of Western Australia," and Mr. Frank orman addressed us in 1937 on "Further contriutions to our knowledge of the Precambrian of Western Australia." In 1945 when I served a revious term as President my address dealt vith "Igneous activity, metamorphism and ore ormation in Western Australia" which really mounts to a consideration of the Precambrian. inally, my colleague Dr. Allan Wilson, now Proessor of Geology in the University of Queensand, in 1958 gave as his address "Advances in he knowledge of the structure and petrology of he Precambrian rocks of south-western Ausralia" in which he reviewed the advances made n our knowledge of the Precambrian shield since he publication of my 1945 address. I am afraid hat we are not working sufficiently fast for me o be able to offer a further contribution with his title so I propose to deal with one of the mportant groups of rocks occurring in our Precambrian—the so-called "greenstones."

One of the most striking features of the eological map of Western Australia published y the Geological Survey of Western Australia in 957 is that the greater part of the southern half f the State is made up of Precambrian granitic ocks within which there are many north-northvesterly trending belts shown in green which re labelled "Archaeozoic Greenstone Phase." ooking more closely at this map we notice that ll of the main gold mining fields are confined o these "Greenstone" belts. Indeed, the Mines Department in 1945 published a mineral map showing the "gold" areas of Western Australia (Fig. 1). These "gold areas," as will be seen on comparing these two maps, are the greenstone belts, for it has been long realised that, from the mining point of view, this is the country where prospecting for gold is most likely to be successful. Indeed, with the exception of the auriferous conglomerates of Nullagine in the vicinity of Marble Bar, no auriferous ore deposit of any significance has been found outside these belts. Little wonder, therefore, that to the mining man in Western Australia "greenstone" has become the most important of the rocks making up this country, and the word "greenstone," used both in the lithological and stratigraphical sense, has become at once the most used and most ill-used of the terms in Western Australian mining and geological publications.

Throughout Western Australian geological literature we continually find reference to fine-grained greenstones, coarse-grained greenstones, massive greenstones, schistose greenstones, greenstone lava schists, altered greenstones, unaltered greenstones, phyllitic greenstones, clastic greenstones, and so on. The use of such names without further petrological data leaves the reader with very little real information about the rock.

The term "greenstone" has also been used in a stratigraphic sense, though not always in conformity with present day usage of stratigraphic nomenclature. Thus, at Kalgoorlie where the Precambrian geology has been the subject of close study since gold was discovered there in 1892 we find that the "Greenstone Phase" of the Archean Kalgoorlie-Yilgarn System consists of the "Older Greenstone Series" and the "Younger Greenstone Series." Indeed, throughout the shield these two distinct episodes of basic igneous activity can be recognised and the rocks have become generally known as the Older Greenstones and Younger Greenstones.

The chaotic state of petrological nomenclature of these greenstones is again evident from the published works dealing with the geology of Kalgoorlie. One of the representatives of the Younger Greenstones has been described at vari-

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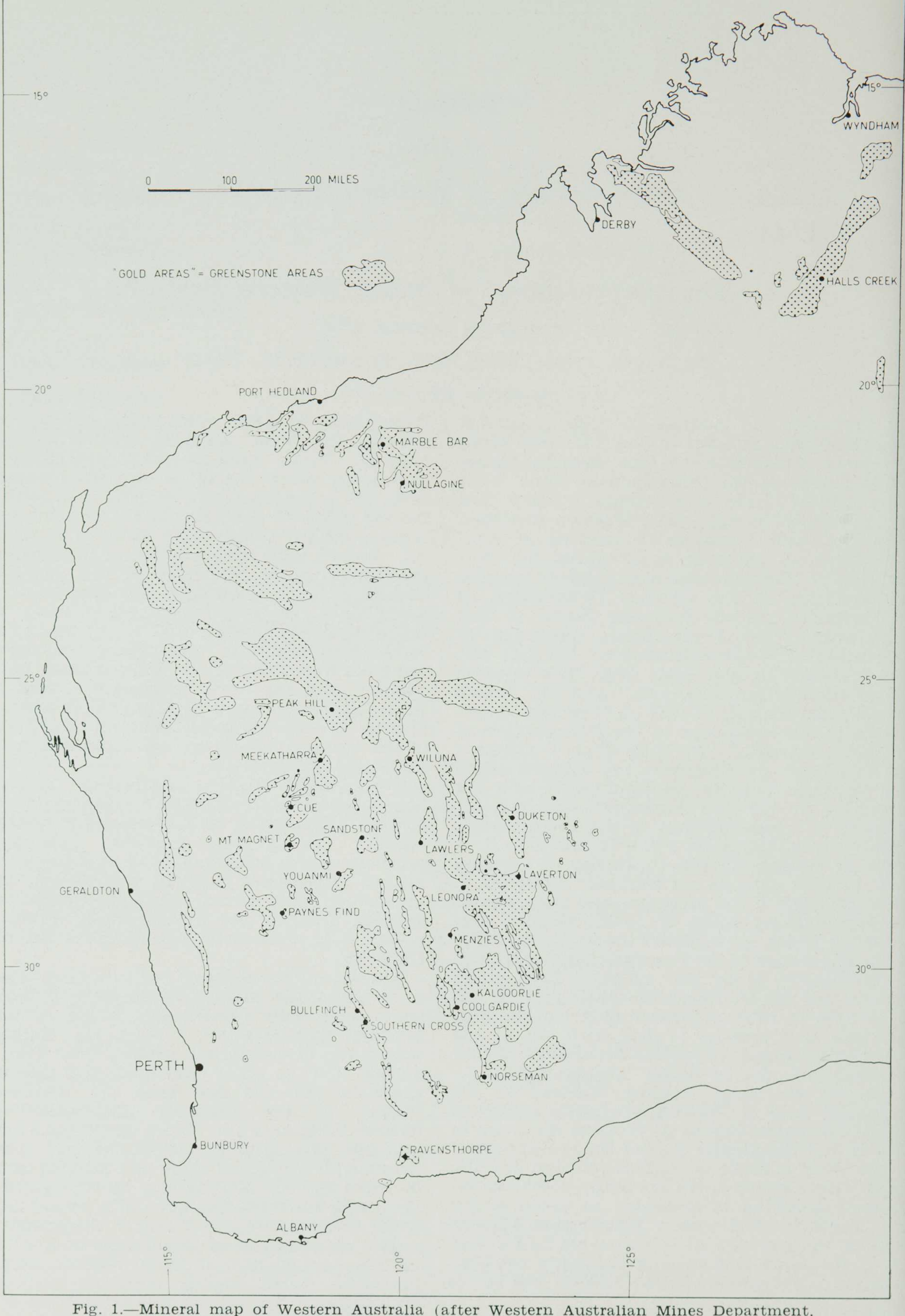

Fig. 1.—Mineral map of Western Australia (after Western Australian Mines Department, 1945) showing "gold areas" (which are the "greenstone areas").

ous times by various geologists as "quartz dolerite amphibolite" (Thompson 1913), "epidiorite" (Feldtmann 1916), "uralitic quartz dolerite" (Stillwell 1928), "quartz dolerite" (Campbell 1953), "unaltered greenstone" (mining geologists in conversation). One cannot wonder at the mining geologist referring to this rock incorrectly as "unaltered greenstone" when so many different names have been given to it as I have indicated.

Many may say "Well, what does it matter?" I feel that it does matter since some of the "greenstones" are favourable host rocks for the auriferous deposits, whereas others are unfavourable. Again, structural mapping is dependent on ability to recognise and distinguish the different greenstones. Moreover, if one understands the origin of the rock he is dealing with he can get a great deal more information from it concerning structure, which is of prime importance in economic geology, than he would otherwise obtain.

I have been prompted, therefore, to look a little more closely at these greenstones in the hope that some order can be put into the present chaos so far as these important rocks are concerned.

Nomenclature

The name Grünstein appears to have been first used in 1787 by Abraham Gottlob Werner of the Frieberg Mining Academy in Saxony as a group name for greenish altered basic igneous rocks.

Greenstone, according to Holmes (1928), is "an old field term applied to more or less altered basaltic or doleritic rocks, the characteristic dark green colour being due to the presence of chlorite, hornblende, epidote, etc. as in diabase and epidiorite." This is the sense in which the term has generally been used. (e.g. Robson 1953), but there are other local usages of the term "greenstone." In New Zealand, for example, it is used as a group name for the fine-grained rocks consisting essentially of either tremolitic amphibole or serpentine, which were used by the Maoris in the manufacture of implements and ornaments (Turner 1935; Reed 1957).

If now we add to these altered igneous rocks the "green beds" of sedimentary origin, together with the products of various kinds and grades of metamorphism on all of these rocks we have the rocks of very varied origin and age, which hitherto in Western Australia, have been referred to as "greenstones." These rocks have, in many cases, been further named meta-dolerites, coarse-grained greenstone, epidioritic dolerite, and so on, as I have already indicated. In many instances they have been incorrectly named—by and large all names of greenstones published by the Geological Survey of Western Australia during the past twenty years are field names and have not been determined after examination with the microscope. In effect, because of lack of petrographic data, the reader is not in a position to determine what these rocks are, other than they are green. So we are still confronted with a greenstone problem which nearly 100 years ago worried the geologist Forbes (1867, p. 57) who said "incorrect views have been formed by persons not much acquainted with petrology and mineralogy from their confounding certain rocks with names which did not, in reality, pertain to them. An example, illustrative of this, may be cited: The writer of these remarks, finding from an examination of the sheets of the Geological Survey that large masses of greenstone were represented as occurring in Cornwall, near Penzance, and at the Botallack mines, immediately imagined that he would there find the same relations of the greenstone to the metallic lodes, occurring as he had found to be the case in South and North America, Spain, Norway, Sweden, etc., and made a journey expressly for this examination; on arrival he at once found that the rocks had evidently been metamorphosed *in situ*, and they no doubt originally had only been the ordinary sedimentary clay-slates. Had he now been content with the decision of the Geological Survey that the rocks in question really were greenstones, then he must at once have come to the conclusion that greenstones could be formed by the alteration of clay-slates *in situ*. It did not, however, require a long examination to prove that the rocks were neither petrologically, mineralogically, or chemically, greenstones, or even any allied rock, being nothing more than clay slates altered *in situ* and possessing none of the properties of greenstones beyond the greenish tinge which coloured them."

Let us look for a moment at the way in which the rocks, which in Western Australia have been referred to as "greenstones" have developed, their characteristics, and their nomenclature. They may be derived from igneous or sedimentary parent materials. Igneous rocks are those which have crystallised from magma and broadly speaking we find the two contrasted types:

(i) The acid rocks which have high silica, alumina, and alkali content and correspondingly low lime, magnesia and iron. These are light-coloured rocks made up largely of minerals such as quartz and felspar with minor amounts of the dark-coloured iron- and magnesium-bearing minerals.

(ii) The basic rocks which have lower silica and alkalies and correspondingly higher iron and magnesia content. They are dark in colour and made up largely of the various ferromagnesian minerals which appear to be black or green in hand specimen.

In both of these contrasted groups we find rocks of varying grain size—where they have cooled quickly, as when extruded from volcanic vents on to the Earth's surface they are fine-grained. Where they have cooled slowly at depth and crystals have had more time to form the grain is coarser-textured. Now we have every gradation between acid and basic rocks according to the chemical composition of the parent magma and the extent to which it has been differentiated, and every gradation in grain size from fine to coarse according to the rate at which cooling has taken place. It is from the rocks of basic to intermediate chemical character that most of our greenstones of igneous origin

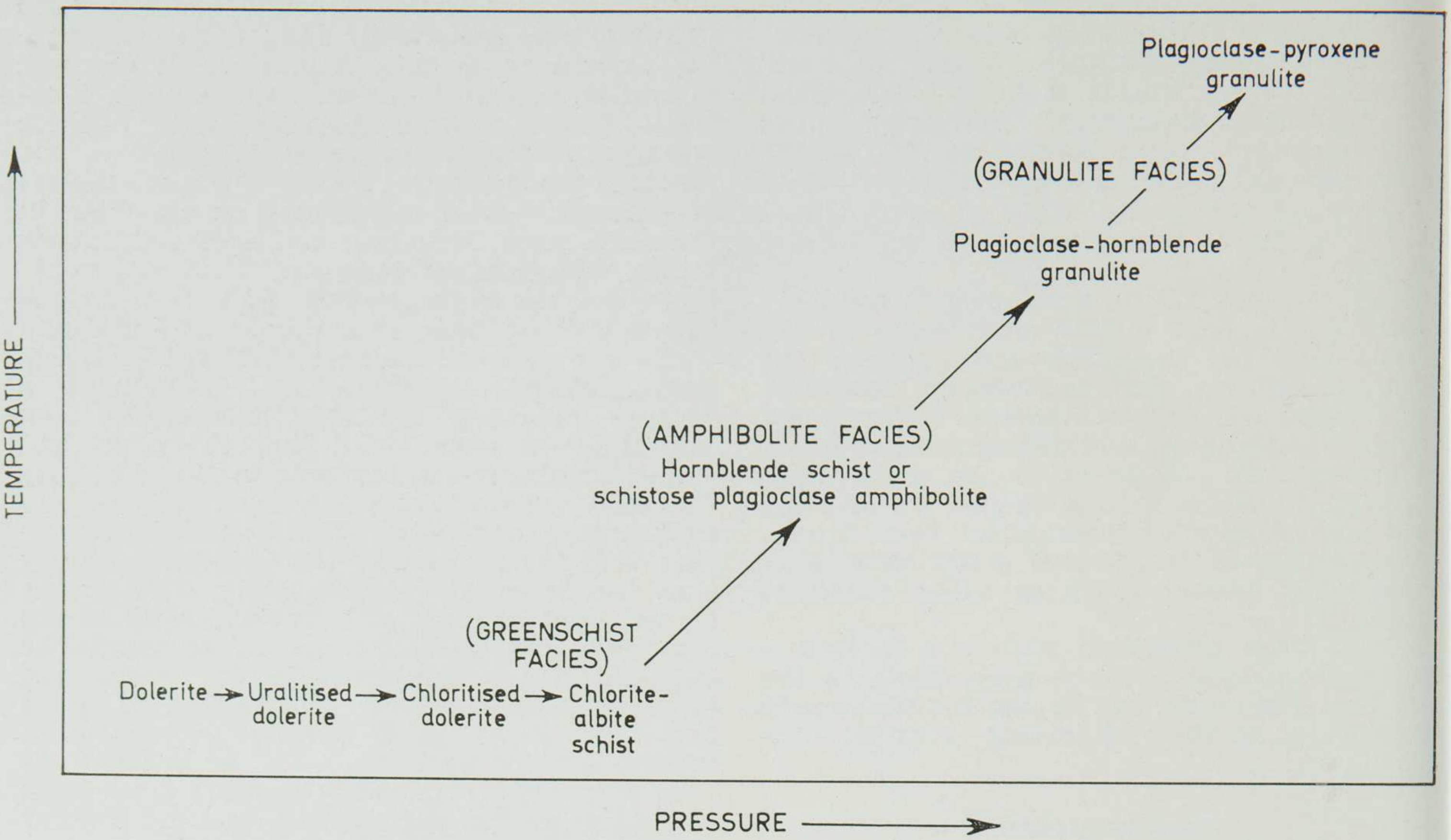

Fig. 2.—Relationship of the metamorphic derivatives of dolerite.

have developed, and the general features of these rocks may be seen by the examination of the effects of different grades of metamorphism on a parent basic igneous rock such as dolerite. Dolerite consists essentially of plagioclase and clinopyroxene. On slight shearing, or under the influence of end-stage liquids during the final phases of consolidation, the pyroxene is converted in varying degree into fibrous green amphibole (uralite) yielding rocks such as slightly to completely uralitised dolerite. In such rocks the original ophitic texture and grain are retained and the original black dolerite is changed to a greenish rock best described as uralitised dolerite. Under higher directed stress the fibrous uralite is converted to chlorite to yield chloritised dolerites. The original textures are still retained at this stage but with further recrystallisation under higher temperature conditions the original textures become obscured and we have the development of the schistose rocks such as the chlorite-albite schists of the greenschist facies. Under conditions of increasing temperature further recrystallisation yields, in turn, the schistose plagioclase amphibolites (hornblende schists) of the amphibolite facies and finally, under high temperature-high static pressure conditions, the plagioclase-pyroxene granulites (such as the basic charnockites) of the granulite facies as indicated in Fig. 2.

Basalts (fine-grained), dolerites (medium-grained) and gabbros (coarse-grained) are all of similar chemical composition and contain similar mineral assemblages and will yield products similar to those already mentioned. So we will find uralitised basalts, chloritised basalts, amphibolites and granulites. In the lower grade metamorphic derivatives (the uralitised and chloritised rocks) the original microstructures and textures may be preserved and the nature of the parent rocks, whether extrusive or intrusive, may be determinable. Once recrystallisation to produce the various amphibolites and granulites takes place these original features tend to disappear and only the larger structures such as pillows and amygdules remain and in the highest grades of metamorphism even these will disappear.

In volcanic areas earlier-extruded lavas such as basalts may be fragmented by later explosive activity yielding a group of clastic rocks (the pyroclastics) which are of similar chemical composition to the parent materials and these, on metamorphism, will result in similar rocks to those I have just mentioned.

Again, the breakdown of these rocks by weathering will yield fragmental products. If this process is slow, chemical weathering will be dominant and the result will be iron-stained clays. If, on the other hand, the breakdown has taken place comparatively quickly, as on a land surface of considerable topographic relief, the resultant sedimentary rocks will be of greywacke type—made up of small rock fragments of the pre-existing rocks in a clayey groundmass. Metamorphism of these clastic materials will produce chloritised greywackes (in which relict clastic textures can still be observed), chlorite schists, and various amphibolites such as hornblende-plagioclase schists and hornblende-plagioclase granulites. The higher the grade of metamorphism, the more the original textures, which indicate the nature of the parent rock, will be obscured, so that it may be very difficult to determine whether the final product was originally igneous or sedimentary in origin.

Another group of "greenstones" is that derived from the ultrabasic igneous rocks. Rocks which originally consisted entirely of olivine or pyroxene, have been converted during metamorphism to a variety of serpentinites, talc-chlorite rocks, and amphibolites. Here again, many of the ultrabasic "greenstones" may well prove to be derived from sedimentary parent materials such as cherty dolomitic limestones.

The Archean Greenstones of South Western Australia

The oldest recognisable rocks in the Western Australian Shield are the rocks of volcanic origin, the so-called Older Greenstone Series, which form the bulk of the greenstone areas of the various goldfields. That these rocks are largely of volcanic origin is evidenced by the presence in them of relicts of the original agglomeratic, amygdaloidal and pillow structures. These are structures which we know from our observations of present day igneous activity are the result of explosive volcanism and extrusion of molten rock material on to the Earth's surface. Of these structures the pillow structure is of particular significance since it indicates the nature of the early Precambrian volcanism and is one of the keys to the present geological structure. When molten lava flows into standing water such as a swamp, a lake or the sea, it breaks up into bulbous masses, spheroidal or ellipsoidal in shape, which settle down on top of one another. These masses being still somewhat plastic take on the shape of the surface onto which they are deposited and the form of the pillows thus provides evidence of top and bottom of the sequence. This pillow structure has been noted in the early Archean volcanics in many localities in Western Australia. The best known occurrences which are at Kalgoorlie (Fig. 3), Norseman and Wiluna recall the pillow structure so characteristic of the Keewatin lavas of the Canadian Shield. These structures may be retained even in completely recrystallised rocks, such as the hornblende schists of Palmers Find near Yellowdine in the Yilgarn Goldfield, and also in completely weathered rocks as at the Transcontinental Railway Line cutting at Kalgoorlie and Mt. Hunt, south of Boulder (Fig. 4). In the Mt. Hunt example figured the rocks have been converted by weathering into a soft friable reddish clay—nevertheless it is still possible to say which is top and bottom of the original flow.

Fig. 4.—Pillow structure in highly weathered steeply dipping Older Greenstones exposed on horizontal surface on west flank of Mt. Hunt, south of Boulder in the Kalgoorlie Goldfield. Top of sequence to the right. (Photograph: R. T. Prider).

Fig. 3.—Pillow structure in carbonated Older Greenstones, No. 5 level, Brownhill Mine, Kalgoorlie. View looking south showing west-facing flow dipping approximately 60° west. (Photograph: G. Scott).

The most closely studied area of Archean greenstones is that of the East Coolgardie Goldfield, particularly in the vicinity of Kalgoorlie, and we might well take Kalgoorlie as the type area for the Archean greenstones. Here we find that there are two distinct ages of Archean greenstones:—

(i) The *Older Greenstones* which were basaltic lavas, in places containing pillow structure indicating that they were perhaps submarine extrusions; an hypothesis which is supported by their soda-rich spilitic character and by the presence locally of interbedded banded ferruginous cherts (jaspers).

(ii) The *Younger Greenstones* which were quartz dolerite and related rocks occurring as concordant (sill or laccolith) intrusions into the Older Greenstones and overlying Black Flag sediments.

The Kalgoorlie Greenstones have been subjected to very intense shearing and the metasomatic activity of CO_2 and siliceous liquids and vapours so that the rocks are now very different from the original basalts and dolerites. Unless one has had extensive experience with these highly metasomatised rocks the microscope is not of very great value for distinguishing the different types of greenstone. In fact, the regional shearing and metasomatism that has affected the Kalgoorlie greenstones tends to reduce them all to a common end-product—a felted aggregate of chlorite, epidote, albite and various carbonate minerals (probably mainly ankerite). If we would determine the original nature of these rocks then we must abandon mineralogical and chemical composition as criteria and rely entirely on relict textures and structures. Some of these—such as the occurrence in the Younger Greenstones of end-stage quartz with apatite needles, relict ophitic texture and leucoxenised ilmenite plates—can be seen with the microscope, but by and large the relict textures in these highly metasomatised rocks are best examined with low magnification on polished surfaces (Fig. 5). No matter how highly carbonated or pyritised these rocks are,

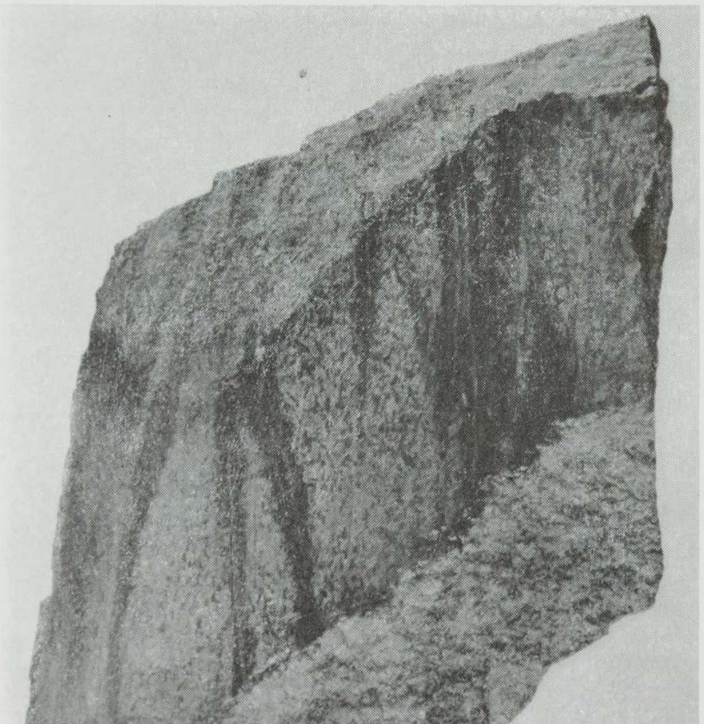

Fig. 5.—Lodestuff (highly sheared, carbonated, pyritised, chloritised quartz dolerite) showing relict textures which are best examined under low magnification on polished surfaces. Central strip of photograph in which the texture is visible is a polished surface of specimen. (X½). (Photograph: K. Bauer).

the original basaltic or coarser doleritic character can be determined in this way—the dolerite derivatives of the Younger Greenstones for example can always be distinguished from the finer grained basalts of the Older Greenstones by the grey skeletal-structured leucoxenised ilmenites.

The Archean Greenstones of Kalgoorlie may be classified as set out in Table I.

The Older Greenstones consist of a sequence of volcanic flows and interbedded pyroclastics. Spilitic flows with pillow structure are characteristic. When naming the rocks the term "basalt" should be further qualified as massive, amygdaloidal, variolitic or pillow-structured according to the structure. There are no unaltered basalts in the Kalgoorlie District. They have all been altered to some extent, culminating in intense carbonation, silicification and pyritisation along shear zones to yield the auriferous lodes.

The intrusive Younger Greenstone magma appears to have been differentiated to yield:—

(i) *Ultrabasics* such as pyroxenites and peridotites now represented by uralitised pyroxenite ("hornblendite"), serpentinites, talc-chlorite-carbonate and fuchsite-quartz-carbonate rocks.

(ii) *Basic rocks* such as dolerite and quartz dolerite and their coarser gabbroic equivalents. Again there are very few of these rocks which carry any relict pyroxene.

(iii) *Porphyries* represented by chloritised hornblende porphyrites and albite porphyries. Some of the so-called albite porphyries or "bedded porphyries" are actually sedimentary rather than igneous rocks and have resulted from the soda metasomatism of claystones by the intrusive basic Younger Greenstone magma to yield adinoles. The intrusive albite porphyry dykes are considered by most authors to be related to a hypothetical granite magma at depth, but I have included them here because of the possibility (Prider 1940) of them being genetically related to the Younger Greenstone magma.

As far as the ultrabasics are concerned, there can be little doubt that the uralitised pyroxenites belong with the Younger Greenstones. The serpentinites, however, may belong to the Older Greenstones. The oldest Precambrian rocks of the Canadian Shield (the Keewatin) and of Southern Rhodesia (the Sebakwian) are basic (often pillow) lavas and serpentinised peridotites like those at Kalgoorlie. Moreover, this association is ubiquitous throughout the Canadian, African and Australian Shields. Hess (1955, p. 399) has pointed to the probable similarity of such widespread basic lava-serpentine associations to the present earth crust beneath the oceans, and it may well be that in these rocks we see an exposure of the primordial earth crust.

These associations of fine-grained greenstones, coarse-grained greenstones and ultrabasics have been recognised in most of the greenstone areas of the Western Australian goldfields. While the Older Greenstones have generally been regarded

TABLE I.

Classification of the greenstones of Kalgoorlie
(Earlier commonly used names are shown in parentheses)

Increasing shear and metasomatism →

	Original rocks	Uralitic stage	Chloritic stage	Carbonated stage	Silicified and pyritised stage
OLDER GREENSTONES	Basalt—massive, amygdaloidal, variolitic or pillow-structured	Uralitised basalt (Fine-grained amphibolite)	Chloritised basalt (Fine-grained greenstone)	Carbonated chloritised basalt and Carbonate-chlorite schist (Bleached fine-grained greenstone and Calc schist)	Lodestuff (do.)
	Agglomerate	Uralitised agglomerate (Fine-grained amphibolite)	Chloritised agglomerate (Fine-grained greenstone)	Carbonated chloritised agglomerate and Carbonate-chlorite schist (Bleached fine-grained greenstone and Calc schist)	Lodestuff (do.)
YOUNGER GREENSTONES	Albite porphyry	Sericitised albite porphyry (Albite porphyry, Albite porphyrite, Keratophyre)		Carbonated albite porphyry	Lodestuff—generally very low grade
	Claystone	Adinole (Albite porphyry)		Carbonated adinole	
	Hornblende porphyrite		Chloritised hornblende porphyrite		
	Quartz dolerite	Uralitised quartz dolerite (Quartz dolerite amphibolite, Epidiorite, Actinolite-zoisite amphibolite, Uralitic quartz dolerite, Quartz dolerite, Unaltered greenstone)	Chloritised quartz dolerite (Quartz dolerite greenstone, Coarse-grained greenstone, Altered greenstone)	Carbonated chloritised quartz dolerite (Bleached quartz dolerite greenstone)	Lodestuff (do.)
	Pyroxenite	Uralitised pyroxenite (Hornblendite)			
	Peridotite	Serpentine	Talc-chlorite rock (Talc-chlorite rock)	Talc-chlorite-carbonate rock (Talc-chlorite-mesitite rock)	Fuchsite-quartz-carbonate rock

as altered volcanics, in some places they contain greenish rocks of sedimentary origin as for example at Edwards Find in the Yilgarn Goldfield and Boogardie in the Murchison Goldfield. These sedimentary "greenstones" are important since sedimentation structures in them, often only visible on examination with the microscope or on polished surfaces, may provide the key to the sequence in these stratified successions. Comparatively few sedimentary greenstones have been mentioned in the literature. Officers of the West Australian Geological Survey in recently published logs of diamond drill holes (e.g. *Bull. Geol. Surv. W. Aust.* **112**) frequently record "clastic greenstones" but in the absence of petrographic information or more specific nomenclature it is impossible for the reader to understand much about either the present or the original nature of these rocks. The use of the terms "clastic greenstone," "metaclastic greenstone," "sedimentary greenstone," and "metasedimentary greenstone" by the same author for rocks from the same drill-hole would appear to indicate some difference between the clastic and sedimentary greenstones.

The presence of green sediments (such as green chloritic sandstones and shales) interbedded with lava flows and pyroclastic beds points to the necessity for more detailed stratigraphic work on these Precambrian rocks than has been carried out in the past. To my knowledge no detailed stratigraphic study of the Older Greenstones has been made other than that recently completed by D. J. Forman (1960) on the greenstones of the country in the vicinity of the Hill 50 Gold Mine at Mt. Magnet. Finucane and Jensen (1953, p. 96) in describing the structure of the Kalgoorlie Goldfield say "Detailed mapping, coupled with increased knowledge of the contained sedimentary horizons, might lead to a clearer definition of the various flows comprising the Older Greenstones, but this work has been beyond the scope of most mining geologists in Kalgoorlie. Moreover, the economics of the great amount of work entailed are doubtful." To this I would say that the Kalgoorlie ore deposits have been studied now for more than half a century and we still do not know why these ore deposits occur at this locality. I feel that more detailed stratigraphic, petrological and mineralogical studies may yet give us this information and when we know the answer to this problem then we will be in an infinitely better position to know where we should search for further ore-bodies. This holds, of course, not only for Kalgoorlie, but for all of the West Australian Goldfields.

The greenstones of the Kalgoorlie District, as I have indicated, have been strongly folded. This deformation must have taken place at during the past 50-odd years we still do not know why the Golden Mile ore-bodies occur where they do—in a "smaller but related structure on the eastern flank of the main structural disturbance" as Campbell (1953, p. 93) describes it. We do not know whether the Golden Mile mineralisation is related to a granitic parent magma (as generally supposed) or whether it is related to the Younger Greenstone magma (as I dared to suggest some fifteen years ago (Prider 1948, p. 63)). It may be that the current age-determination work may yield the answer to this question.

Coming back more specifically to the "greenstones": I have indicated that our knowledge of the goldfields greenstones is very meagre and that there has been little addition to our knowledge of these rocks over the last 30 years in spite of the fact that extensive mining operations and diamond drilling programmes, both private and governmental, have offered us an abundance of material to work on. This is due to the lack of first-class petrological work on these rocks—to the fact that during this period there has been no qualified petrologist on the staff of the Geological Survey Branch of the Mines Department which is actively engaged in mapping the goldfields areas and carrying out diamond drilling programmes. I am not belittling the work of the field geologists of the Geological Survey. It will be apparent to all that the greenstones are very varied in origin, for the most part difficult to determine with surety and, in the mining areas where they are of greatest interest, they have generally suffered low grade metamorphism and extensive metasomatism which further obscures their origin. When dealing with such rocks as these, the field geologist needs a specialist petrologist to guide him. It is my belief that the appointment of a highly qualified petrologist to the staff of the Geological Survey would double the efficiency of every member of the field geological staff, bring us a long way towards putting order into the greenstone chaos of which I have spoken this evening, and, what is most important so far as the mining man is concerned, go a long way towards finding more ore.

References

Campbell, J. D. (1953).—The Structure of the Kalgoorlie Goldfield. Geology of Australian Ore Deposits (5th Emp. Min Met. Congr.): 79-93.

Clarke, E. de C. (1923).—The Pre-Cambrian System in Western Australia. *J. Roy. Soc. W. Aust.* 9: 13-37.

Feldtmann, F. R. (1916).—The Geology and Ore Deposits of Kalgoorlie, E. Coolgardie G. F., Part III. *Bull. Geol. Surv. W. Aust.* **69**.

Finucane, K. J., and Jensen, H. E. (1953).—Lode structures in the Kalgoorlie Goldfield. Geology of Australian Ore Deposits. (5th Emp. Min. Met. Congr.): 94-111.

Forbes, D. (1867).—On the alleged hydrothermal origin of certain granites and metamorphic rocks. *Geol. Mag.* 32: 49-59.

Forman, D. J. (1960).—Stratigraphy of the Boogardie Group. *J. Roy. Soc. W. Aust.* **43**: 83-96.

Forman, F. G. (1937).—A contribution to our knowledge of the Pre-Cambrian succession in some parts of Western Australia. *J. Roy. Soc. W. Aust.* 23: xvii-xxvii.

Hess, H. H. (1955).—Serpentines, orogeny and epeirogeny. *Spec. Pap. Geol. Soc. Amer.* **62**: 391-408.

Holmes, A. (1928).—"The Nomenclature of Petrology." (Murby: London.)

Maitland, A. Gibb (1927).—The volcanic history of Western Australia. *J. Roy. Soc. W. Aust.* **13**: 79-86.

Prider, R. T. (1940).—A note on the age relations of the basic porphyrites and albite porphyries of the Golden Mile, Kalgoorlie, Western Australia. *J. Roy. Soc. W. Aust.* **26**: 99-101.

Prider, R. T. (1941).—The contact between the granitic rocks and the Cardup Series at Armadale. *J. Roy. Soc. W. Aust.* 27: 27-55.

Prider, R. T. (1948).—Igneous activity, metamorphism and ore-formation in Western Australia. *J. Roy. Soc. W. Aust.* **31**: 43-84.

Prider, R. T. (1958).—The granulites and associated rocks of Galena, Western Australia. *Aust. Inst. Min. Met.* (Stillwell Anniv. Vol.): 189-211.

Reed, J. J. (1957).—Use of the terms Greenstone, Nephrite, Bowenite and Jade. *J. Polynes. Soc.* **66**, No. 2.

Robson, J. (1953).—The Cornish "Greenstones." *Trans. R. Geol. Soc. Cornwall.* **18**: 475-492.

Stillwell, F. L. (1928).—Geology and ore deposits of the Boulder Belt, Kalgoorlie. *Bull. Geol. Surv. W. Aust.* **94**.

Thompson, J. A. (1913).—On the petrology of the Kalgoorlie Goldfield (Western Australia). *Quart. J. Geol. Soc. Lond.* **69**: 621-677.

Turner, F. J. (1935).—Geological investigation on nephrites, serpentines, and related "greenstones" used by the Maoris of Otago and South Canterbury. *Trans. Roy. Soc. N.Z.* **65**: 187-210.

Wilson, A. F. (1952).—Diopsidization and hornblendization—important metasomatic phenomena in the basic schists near Southern Cross, Western Australia. *J. Roy. Soc. W. Aust.* **37**: 97-103.

Wilson, A. F. (1958).—Advances in the knowledge of the structure and petrology of the Precambrian rocks of south-western Australia. *J. Roy. Soc. W. Aust.* **41**: 57-83.

Wilson. A. F. (1959).—The charnockitic rocks of Australia. *Geol. Rdsch.* **47**: 491-510.

Woodall, R. (1954).—Amphibolites and associated Pre-Cambrian rocks of part of the Phillips River Goldfield, Western Australia. *J. Roy. Soc. W. Aust.* 39: 1-17.

comparatively shallow depths under low temperatures as the rocks have not been recrystallised. They contain relicts of their original texture which enable us to determine their origin. In some places, however, the Archean greenstones have been more highly metamorphosed and are now represented by completely recrystallised metamorphic rocks such as hornblende schist (as in the Yilgarn Goldfield) and coarse hornblende granulite (as in the Wheat Belt). In these more highly metamorphosed rocks recrystallisation tends to obliterate the primary textures so that only the larger structures such as amygdules and pillows remain and at the highest grades of metamorphism even these disappear. I have already noted in my Address to this Society in 1945 how the grade of metamorphism appears to vary according to the distance from the margins of the greenstone belt and also according to the size of these greenstone areas (Prider 1948, p. 58). Thus the greenstones at Kalgoorlie which lie in the centre of an area of 8,000 square miles of greenstones have suffered lower grade metamorphism than those at Coolgardie and Gibralter which are near the margins of this large greenstone area. Again, the Yilgarn Goldfield is a much smaller body of the Archean greenstones and has been more highly metamorphosed than the Kalgoorlie area and the greenstones are represented by various plagioclase-hornblende schists in which relict pillow structures may be seen in places. Still farther west, in the Wheat Belt, the areas of greenstone are even smaller and much more highly metamorphosed. Here we come to the higher amphibolite and granulite facies where the original structures, both megascopic and microscopic, have been largely obliterated by recrystallisation under high temperature-high pressure conditions to yield coarse plagioclase-hornblende schists and granulites, plagioclase-hornblende-pyroxene granulites and charnockitic granulites (Wilson 1959, p. 499). A notable feature is the occurrence of meta-jaspilites associated with these granulites. It is impossible to determine whether the basic granulites were originally extrusive basic volcanics (basalts and agglomerates), basic igneous intrusions or basic sediments such as greywackes, but the associated jaspilites are strong evidence that originally they were similar to the sequences developed in the various goldfields areas further east. Indeed, so far as we can say at the present, they are the representatives in the western part of the Shield of the Archean greenstones of the goldfields areas.

The Late Precambrian Greenstones

Included here are those rocks which have been referred to as "greenstones" which are younger than the granites of south Western Australia. They fall into two groups:—

(a) The basaltic lavas interbedded with the sediments of the Proterozoic Nullagine System and

(b) The altered basic igneous intrusives into the granites and Nullagine System.

There is but little information available concerning the basaltic rocks interbedded with the Nullagine sediments. They have been recorded from a number of localities such as Braeside in the Pilbara, the Warburton Ranges near the South Australian border and from the Darling Scarp where the Cardup Shale contains a conformable albite-chlorite epidiorite sill or flow which is older than the dolerite dykes of this area (Prider 1941, p. 43).

The younger group is represented by altered dolerite dykes which have been intruded into all of the Precambrian rocks, including the Nullagine sediments. Earlier writers generally referred to these as "greenstone" dykes but more lately they have been described generally as dolerites or epidiorites. These dolerites have often been so completely uralitised that they are indistinguishable from the uralitised quartz dolerites of the Younger Greenstones of the goldfields areas. Indeed the epidiorites of the Darling Range near Perth can be matched in everything except age, with representatives of the Younger Greenstones of many mining fields. There have been no further contributions to our knowledge of these rocks since the publication of my 1945 Address other than my work (Prider 1958) on the quartz dolerite dyke swarm of Galena near Northampton.

The main economic significance of these late Proterozoic or early Palaeozoic basic dyke intrusions is that they are quarried for road metal and concrete aggregates. They appear also to be genetically related to the lead ore deposits of Northampton and Galena and various places in the Darling Scarp where small uneconomic deposits of lead ores occur. Their economic significance in auriferous areas is that they commonly cut and displace the ore bodies, and careful study of them may aid location of the displaced sections of such ore bodies.

Conclusion

Archean greenstones are the most important country rocks of the auriferous deposits which have played such an important role in the development of this State. I am very disturbed that my readings have lead me to the conclusion that our knowledge of these rocks is very meagre. While a good deal of valuable work has been done on the granulite facies greenstones of the Wheat Belt there have been very few worthwhile contributions made to our knowledge of the goldfields greenstones during the past thirty years other than those of Wilson (1952) and Woodall (1954). Mining geologists have, by and large, focussed their attention on the ore-body and have tended to overlook the significance of the country rocks and the information they may afford concerning the genesis of the ore-body. It seems to me that emphasis in connection with ore search has been placed entirely on geological structure as mapped from drag folds and related tectonic structures without any detailed consideration of the lithology. I believe structure to be of great importance but I also believe that if we know more about the greenstone country rocks we shall be better able to map structure and interpret its significance in the formation of the ore-body. Equally important is the information that research may yield concerning the origin of the ore-body. I have already pointed out that in spite of intensive work